§21. Observation of Spontaneous Toroidal Flow in LHD

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A moderate velocity shear of plasma flow is considered to play an important role to suppress turbulence and reduce transport, although a large velocity shear cases Kelvin-Helmholtz instabilities. Thus the measurement of radial profiles of flow velocity is important in the study of plasma confinement. Because the toroidal flow is coupled with poloidal flow through viscosity tensor, the toroidal flow determined by not only toroidal momentum driven by NBI and momentum transport but also by toroidal forces driven by poloidal flow and radial electric field through viscosity tensor. The profiles of toroidal flow velocity are measured with charge exchange spectroscopy (CXS) with tangential view using the emission from carbon impurity (CVI).

The magnetic field strength is 2.75T and the major radius of the magnetic axis is Rax=3.6m in this experiment. The plasma is produced initially by electron cyclotoron heating with hydrogen gas and sustained with tangentially injected n-NBI with negative ion source and perpendicularly injected p-NBI with positive ion source. The line averaged electron density and central electron temperature is $1.6\mathrm{x}10^{19}\mathrm{m}^{-3}$ and 2.5 keV, respectively. The n-NBI is also used to control the momentum injection in tangential direction which drives the troidal flow directly, while the p-NBI is used as a probe beam for CXS as well as the ion heating.

Figure 1 shows the radial profiles of the troidal flow velocity in the plasma with co-injected and counter-injected NBI. The differences in toroidal flow velocity between these two discharges are considered to be the toroidal flow driven by momentum injection from n-NBI. The toroidal flow driven by the n-NBI is localized near the plasma center (ρ < 0.4) because the beam deposition profile is peaked at the plasma center and the toroidal viscosity, which plays as a drag of toroidal flow, significantly increases towards the plasma edge. The toroidal flow in the counter direction is observed off the plasma center (ρ > 0.4) even in the plasma with co-injection. Because the magnitude of this counter rotation does not depend on the direction of n-NBI injected, the toroidal flow is considered to be a spontaneous toroidal rotation driven by the coupling between toroidal and poloiadl flow through viscosity tensor. Figure 2 shows the radial profiles of radial electric field in the plasma similar to that plotted in Fig.1. The positive radial electric field is observed in the plasma with both the co-injected and counter-injected of NBI. In helical plasma the positive radial electric field drives spontaneous toroidal flow in the counter direction due to viscosity tensor because the plasma tends to flow along the minimum gradient B direction, which is in contrast to the fact that the positive radial electric field drives spontaneous rotation in the co-direction.

In summary, the toroidal flow observed in LHD is dominated by the toroidal flow driven by NBI near the plasma center, while it is dominated by the spontaneous toroidal flow outer region of the plasma. The spontaneous toroidal flow observed is in the counter direction when the radial electric field is positive in the electron root plasmas. This result is consistent with the experimental results in CHS[1] and considered to be common characteristics in Heliotron plasma, where the pitch angle of minimum gradient B is always larger than the pitch angle of magnetic field averaged in magnetic flux surface.

Reference

1) Ida, K., et.al., Phys.Rev.Lett **86**, (2001) 3040.

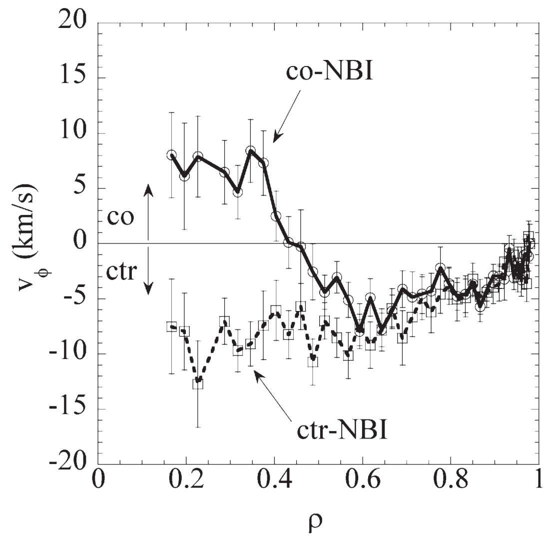

Fig. 1. Radial profiles of troidal flow velocity in the plasma with co-injected and counter-injected NBI. Positive (negative) toroidal flow corresponds to the toroidal flow parallel (anti-parallel) to the equivalent toroidal plasma current which produces the poloidal magnetic filed due to the external current in helical coils.

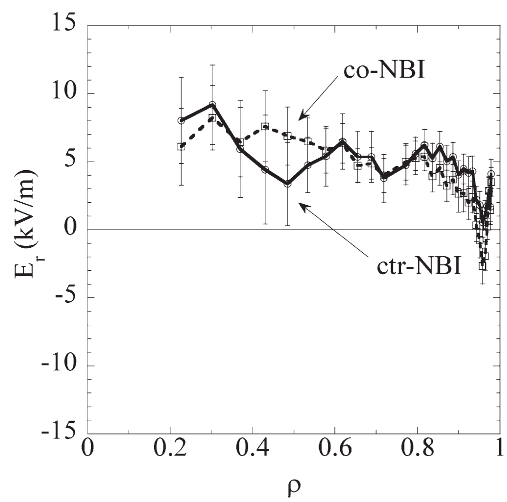

Fig. 2. Radial profiles of radial electric field in the plasma similar to that plotted in Fig.1.